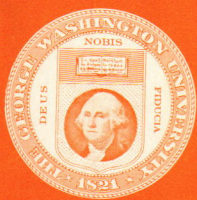


MECHELECIV

THE STUDENTS MAGAZINE • VOL. 28 • MAY 1970 • NO. 6
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SAN FRANCISCO'S PUNCH-CARD IRON HORSE - PAGE 4

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FEATURE ARTICLE

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COVER

Artists conception of rapid transit terminal.

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Computer art.

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SLANT NO. 1
— Auro Lecci

A subroutine provides random numbers that are used to influence decisions concerning all factors except the slope and the distance between neighboring lines inside blocks, which are pre-determined. Three decision levels are to be found in the program. The first is concerned with predetermining the length of the entire drawing along the X-axis. The second is concerned with decisions related to the length of the lines along the Y-axis and the number of times each line is to be repeated to form a block. The third controls connections between blocks and decides on the length of jumps, if any. All these decisions are taken at random, and each run through the computer gives a remarkably different pattern. Produced with an IBM 7090 computer and a CalComp plotter.

MECHELECIV

HEY...WHAT'S GOING TO HAPPEN TO THE D-H HOUSE?

The idea of a new library is very exciting and the students of SEAS feel it is a most needed addition to the University. Unfortunately, the engineers on campus are feeling the University's growing pains as their House is scheduled to be leveled before February '71 to make way for that new library.

It is important for the University to understand the value of an Engineers' House on campus. For seventeen years the House has been used by undergraduate and graduate students alike for use as a place to study and hold meetings. The Engineers' Council, IEEE, ASCE, ASME, Theta Tau, Sigma Tau, and Tau Beta Pi have used the House to its best advantage by offering tutoring services and establishing the only ham radio station on campus. New programs for tutoring inner city students are under-way. The House is used an average of twenty hours per week for studying and other activities.

The question now is what will replace this invaluable center for the engineering students of SEAS. At present, the University has approved the temporary use of Building 'U'. The extra space can well be used, but the students are most uneasy about the impermanent conditions. Most of them feel that the University will leave them without an adequate building, although Mr. Einbinder has assured the Dean that there will be an "attempt to find suitable replacement quarters for the activities housed." The students feel that they deserve a more definite commitment than this from the University in the way of a concrete proposal. The Engineers' Council as the governing body of the students of SEAS will be meeting with the University to reach an equitable solution.

DONALD E. WALLROTH
President, Engineers' Council

SAN FRANCISCO'S

PUNCH-CARD

IRON HORSE

BY

SIDNEY J. HARMON

San Francisco's Bay Area Rapid Transit (BART) is the first completely new metropolitan rail transit system in the nation in 60 years and the first in the world to be completely automated.

BART is a regional rapid transit network built as an integral part of the total transportation facilities of the San Francisco Bay area, serving San Francisco, Alameda, and Contra Costa counties. (Figure 1) The system includes 23

miles of underground and underwater construction, 25 miles of aerial construction, and 27 miles at grade — a total of 75 miles, double track. Thirty-four passenger stations are located at points that offer the most convenience to the public.

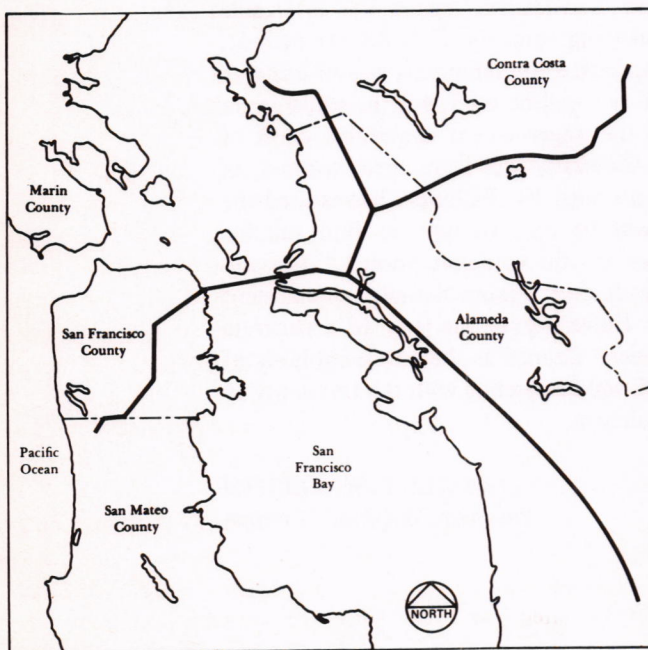
The Bay Area Rapid Transit District was created in 1957 by California's state legislature. In 1962, voters in three counties approved a \$792 million bond issue to pay for the basic rail network. Popular support came from a desire for an alternative to further expansion of expressways that destroy property while failing to relieve congestion; at least 30 expressway lanes would be needed to match BART's design passenger capacity.

Additional funds to meet the \$1.3 billion in capital costs are coming from Bay Bridge vehicle tolls (\$180 million), federal agencies, the state legislature, and passenger fares. Expected to range from about 25¢ to \$1 for the longest one-way ride, fares will also cover system operating costs.

The first segment of the system — a 23-mile stretch from Hayward to downtown Oakland — will be in operation in 1971; the entire system is scheduled to be in operation in 1972.

BART will have as many as 105 trains in operation during peak hours, running on headways as close as 90 seconds through the Oakland "Y" area (MacArthur to 12th Street). The 72-passenger cars assembled in trains up to 10 cars long will be operated at speeds approaching 80 mph, with absolute passenger safety. Average speed, including 20-second station stops, will be 50 mph — about twice as fast as any existing urban transit system.

The world's first computer-supervised transit control system will make the many BART trains operate as a



The first completely new metropolitan transit system in 60 years, BART will serve three counties in the San Francisco area. (FIGURE 1)

coordinated system, rather than as independent units constantly interfering with one another. It will operate the vehicles and supervise train scheduling and routing while automatically preventing collisions. Past attempts at such coordination have used nothing more complex than a fixed-program train director, which would not be at all flexible enough to run a system like BART with maximum efficiency.

The BART control system will keep the trains on schedule to the degree possible. As unavoidable delays occur, however, it will continually adjust the schedule of each train to maintain a spacing that minimizes passenger waiting time at the various stations.

The system includes a central control complex, located adjacent to the BART administration building near downtown Oakland, local control units at the 34 stations and at the train yards, car-mounted control packages, and the communications equipment required to link the system together.

The local control units are used for control of all functions of the transit system relating to safety, such as protective train spacing, overspeed prevention, and the locking of switches to prevent misrouting. The central computer control is used for coordinating functions such as system optimization. The safety functions of the local system cannot be overridden by the central computer, but some nonsafety functions also performed by the local system, such as station dwell time, normally will be overridden by the central computer in the process of optimizing system service.

The train control and communications system is being provided under a \$26 million contract by the Westinghouse Electric Corporation, the largest single BART contractor with system-wide responsibilities.

Under a separate subcontract from the BART car builder, Rohr Corporation, Westinghouse is providing all elements for movement and electrification of the system's 250 initial cars, including propulsion and propulsion control equipment, brakes, trucks complete with wheels and axles, air suspension, air conditioning, and auxiliary power.

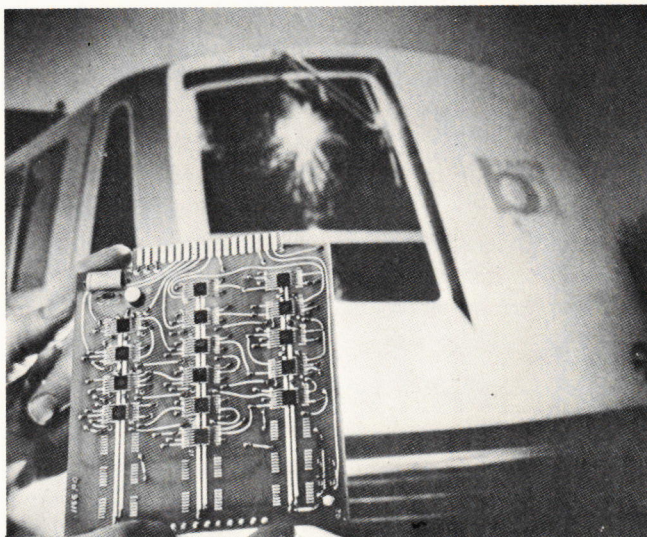
TRAIN CONTROL AND COMMUNICATIONS

The concept of automated train control developed by BART engineers combines for the first time all the functions required to operate trains without human intervention: regulation of individual train movement from starting to stopping; determination of the routes the trains will take; and control of scheduling to keep trains spaced for optimum station service.

Train acceleration and braking is smooth, safe, and fully automatic. The trains stop precisely at the platforms and open and close their doors, without human assistance. A

train attendant will be on board, however, and will be able to press a button to bring the train to a stop in an emergency.

Between stations, trains are under the direct control of a new system of train protection based on modern information theory and solid-state components (Figure II). When this concept demonstrated its feasibility in early 1967, it became the basis for Westinghouse's low bid because it substantially reduced the cost of installation and equipment.



This integrated-circuit logic board is one of hundreds used in the control system directing trains like the one in the background along BART's 75-mile transit network at speeds up to 80 mph as frequently as every 90 seconds. (FIGURE II)

The system relies on dependable track circuits (electrical signal paths that use the steel track as a conductor) to detect whether a given block (section of track) is occupied and, based on this knowledge, to lock switches and to deliver speed commands to the trains. Each track circuit constitutes a block. Speed signals come from a wayside transmitter at the end of each track circuit, coupled to the track by an electrical inductive loop. The signals are in the form of a digital code created by frequency-shift keying of audio frequency signals, a coding method that isn't affected by interference.

On each train, receiving equipment decodes the signals and converts them into control commands for equipment on each of the cars.

As a train approaches a station platform, a signal from a special control system is superimposed on the block signal and brings the train to a stop within five feet of target. An encapsulated flat cable, with two conductors crossed over each other every foot, is laid along the rails at each station. An antenna on the train senses this cross-over and produces a distance measurement independent of wheel rotation. A

stored program computes the distance to go and controls braking to a smooth, precise stop. The train doors then open automatically for a period determined by the central control — normally for 20 seconds, unless scheduling adjustments are being made.

From his location at the front end of the train, the attendant can keep watch for any unusual obstacles in its path. He is also available to answer passenger questions and to take action if any special problem situation occurs within the train. In addition to the emergency stop button, his control panel provides for low-speed manual operation, if necessary, after an emergency. He can also operate the doors manually. Normally, however, he just keeps watch and stays in touch with the central control room by radio telephone.

A high-speed digital telemetry system provides communications between the central control complex and 45 local terminals which monitor the field devices. The telemetry equipment operates at 1200 bits per second, allowing the computer to scan each of the 8000 telemetry points on the system at least once every half second.

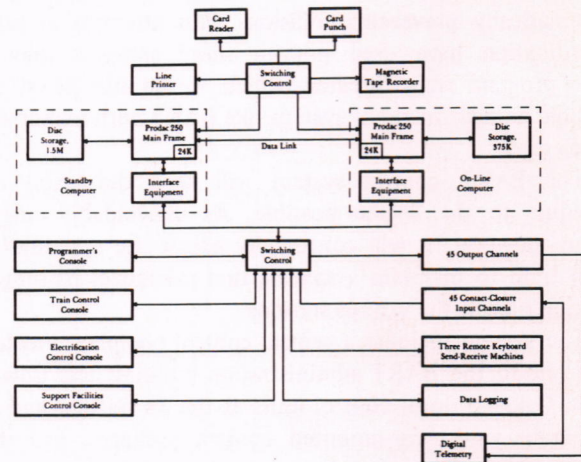
CENTRAL CONTROL COMPLEX

Located on two underground levels adjacent to the Lake Merritt Station near downtown Oakland is BART's central control complex. It is actually an underground extension of the BART administration building, also being built at the Lake Merritt site.

The central control complex consists of two Westinghouse Prodac 250 computers and associated peripheral and support equipment (Figure III). One of the computers, the on-line unit, supervises scheduling and monitors the operation of the network. The second computer, the standby unit, provides complete backup for the on-line unit as well as simulation of the system for off-line experimentation and for operator training.

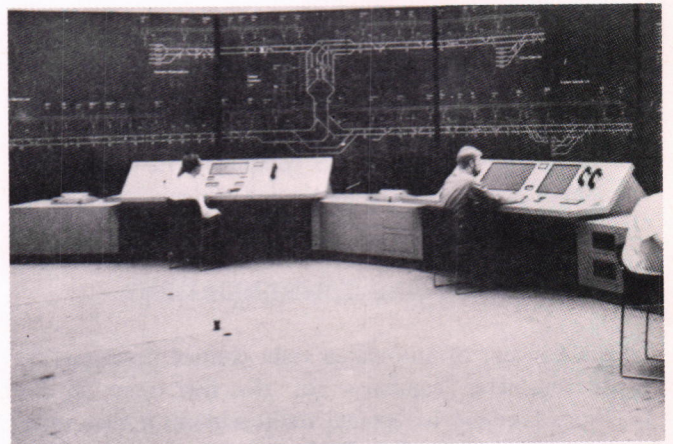
Guided by the operating schedules, the computer checks for correct train makeup, determines departure times from yards and stations, and sees that the trains are properly routed. It requests train speed adjustments and makes other corrections to ensure a high standard of service throughout the system. Some of these corrective strategies are: distribute the intervals between trains, adjust station dwell time, control the sequence of trains, and revise train dispatch schedule.

The computer keeps track of train speeds and schedules and displays these on request. For maintenance purposes, it keeps records of accumulated car miles and operating hours by coupling train identification numbers with automatic car identification data from cars departing the yards. The computer can also analyze system power consumption based on data brought in from remote sensors.



Equipment at BART's central control complex is linked through its two computers. (FIGURE III)

In addition, the computer monitors the operation of equipment such as fans, vents, circuit breakers, and pumps. In case a unit malfunctions, the computer alarms the



The facilities in BART's central control room supervise and control the entire transit network. The room has three control consoles with associated display panels. From the left, they are system electrification, support facilities, and train control. (FIGURE IV)

Continued on page 13

THE MECHELECIV

LETTERS TO THE EDITOR

Dear Sirs:

I would first like to commend the instructor of ApS 1 and 2 for a job well done considering the circumstances of it being taught for the first time this year. I feel that it almost fulfilled the framework in which the course was brought into being.

After talking with some of my fellow freshmen and some upper-classmen, I have come up with the following suggestions for the instruction of the course next year.

The first is that some of the lectures of the course should be taught by the upper-class students. This would give the incoming freshmen a view of what the work is really going to be like in the years that follow since they themselves had been freshmen not too long ago, they will have a better understanding of the freshmen's problems and how to prepare him for the work that is to follow in the years to come.

Another thing that has been talked about is that not enough students know the full use of the slide rule (logs, sines, etc.).

One more point is that, though the lectures we had this year were good, they did not actually give the freshmen an idea of what it would be like to be an electrical, civil, or mechanical engineer. I feel that the solution to this problem would be to have some lectures from engineers who have just graduated and who can still communicate with the freshmen.

Movies and even a seminar in environmental engineering would round out a good freshmen orientation into the field of engineering.

Signed,
Jay Rubin

Dear Sir:

For the lucky engineering student who has managed somehow to stay in S.E.A.S. for three years or more; he has had the opportunity to see some of the greatest curriculum

changes of all times. But, alas, the honorable guardians of our education (faculty *and* administrators, I didn't want to leave anyone out of recognition) have outdone themselves this time. After the junior EE students had miraculously adjusted their schedules for this Fall after being surprised by a fabulous curriculum change that happened over last summer without the students being informed, the EE department decided to make next year's senior EE labs only two credits each. Now, if you're affected by this new innovation and have been following the curriculum in last year's catalogue, you will find that you still need three credits for your humanities requirement plus two more credits created by the changing of the senior EE labs from three to two credits apiece. But don't worry yourself; you only have six courses to take next year each semester plus two to five credits in humanities this summer (or next year if you're a masochist) to make one hundred and thirty credits required for graduation. Now unless you're a transfer student or some kind of freak who has more than 24 or so credits in humanities by the end of five semesters, you have been zonked again by progressive education.

Now, if you're a full time junior EE student and now plan to take these newly conceived credits this summer, may I suggest to you that it is morally and philosophically proper that you charge your summer school tuition to S.E.A.S.

You didn't want to get sand in your shoes at the beach this summer, anyway, did you?

Signed,
The Watcher



LETTER TO THE EDITOR POLICY. The opinions set forth in the "Letter to the Editor" page of this magazine are not necessarily the opinions of the staff of *Mecheleciv* magazine. This page is set aside each issue for use by students, alumni, faculty, and staff of the School of Engineering and Applied Science. The staff will also accept letters from other sources if the letters concern the magazine or would be of interest to the students, alumni, faculty, and staff of the S.E.A.S. *Mecheleciv* reserves the right to edit any letter if lack of space deems it necessary. If, in the opinion of the Editorial Staff of *Mecheleciv*, a letter appears to be unprintable, the staff reserves the right to return the letter to the sender stating the staff's reasons for withholding it from publication. All letters must be signed; however, pen names may be substituted if requested.

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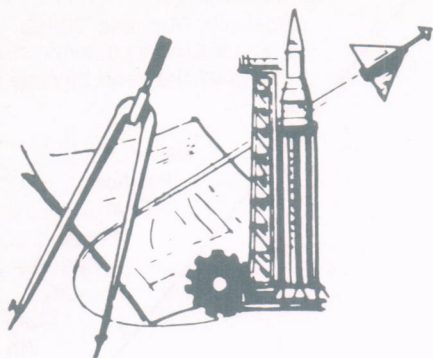
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Or, write to Hewlett-Packard, c/o Dick Singer, 2 Choke Cherry Road, Rockville, Maryland 20850. Phone (301) 948-6370 collect. Prices: HP 9100A Calculator \$4400; HP 9100B Calculator \$4900. Peripherals; HP 9120A Printer \$975; HP 9125A X-Y Plotter \$2475. Lease/rental programs start as low as \$1.50/computing hour, based on average usage.

090/1B

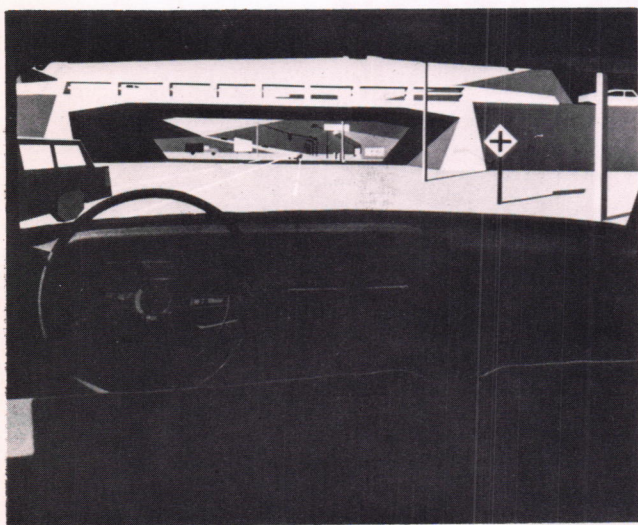
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HP CALCULATOR SYSTEM 9100



TECH NEWS

Edited by Gregory D. Smith



A General Electric Computer Perspective Image Generalization system presents a realistic highway scene to a "driver" who sees the scene change as he guides his "vehicle".

HIGHWAY SAFETY THROUGH G.E. COMPUTERS

The problem of making highways safer, even as the number of cars increases, is being attacked by General Electric with computer technology and visual display panels much like TV screens.

The technique, called Computer Perspective Image Generalization, utilizes computers linked to the accelerator, brake pedal, steering wheel and other controls and instruments inside a mockup automobile. A typical highway scene, programmed into the computer, is displayed on a screen in front of the driver.

Because of the coordinated nature of the computerized system, conditions change as the driver controls his "vehicle". If he accelerates, objects on the screen move toward him at increased speed. If he steers around a curve, the scenery changes as though he were actually rounding a bend.

Rather than use movie films and models, the system uses the computer to simulate the highway environment in

which the driver "travels". The system shifts the environment picture as soon as the driver makes a change in the controls.

Realistic traffic situations can be simulated by placing moving "vehicles" on the screen, thus introducing the problem of avoiding other "cars" with unpredictable "drivers" at the wheel, just as in real life.

The computer makes a minimum of 10 million calculations a second to provide a smooth sequential picture as the driver moves down the road.

Currently the University of California at Los Angeles (UCLA) is determining how the GE system can be used best in highway safety research. The university awarded a \$74,000 study contract for the work to GE's Apollo Systems Department in Daytona Beach, which in turn is using the company's Electronics Laboratory in Syracuse, N.Y., for technical performance of the contract. It is part of a contract undertaken by UCLA for the U.S. Department of Transportation.

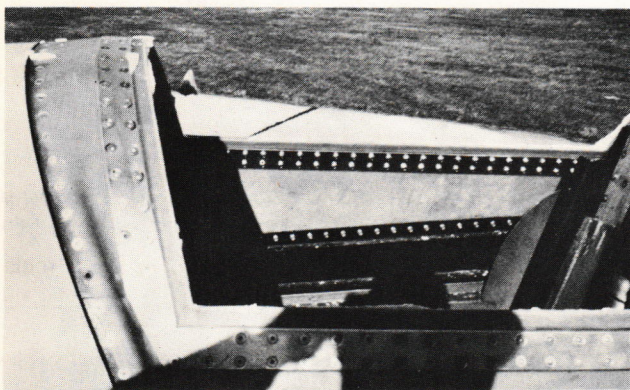
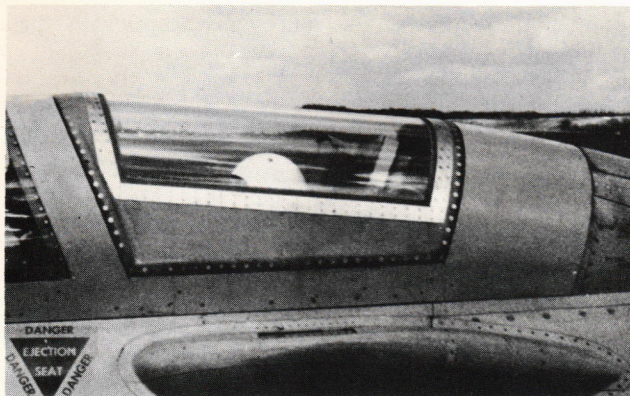
The computer Image Generation Equipment, developed at GE's Electronics Laboratory, already has been used for other applications, including systems supplied to the U.S. Navy at Point Mugu, California, to study aircraft pilot behavior, and to NASA's Manned Spacecraft Center in Houston, Texas, to evaluate spacecraft control systems.

CORNING'S COMMAND-BREAK GLASS TESTED FOR SAFER AIRCRAFT CANOPY

An aircraft canopy system that can mean safer ejection procedures for crew members during emergencies makes use of a special command-break glass from Corning Glass Works. Corning said the canopy glass breaks into minute, blunt-edged particles as it virtually disappears when a break is initiated.

This means that pilots and crew members could eject themselves directly through the glass for faster and safer emergency escapes rather than carry out the more time-consuming procedures now required with plastic canopies. Ejecting through the glass eliminates the delay necessary in current systems to blow off the canopy prior to escape — a

THE MECHELECIV



Command-break glass developed by Corning Glass Works for use in an aircraft canopy system breaks into minute, blunt-edged particles and virtually disappears when a break is ordered. In emergency situations, pilots and crew members could eject themselves directly through the canopy for the fastest possible escape.

time lag that could spell disaster in high-speed, low-flying aircraft.

The new glass also eliminates the possibility that a crew member will have to eject himself through a malfunctioning plastic canopy. When this occurs there is a high probability of severe or fatal injuries.

In a series of ejection tests recently completed by the Air Force at Wright-Patterson Air Force Base, Dayton, Ohio, dummies were ejected through the new glass canopy under static, taxi and flight conditions. The canopies were installed in an F101B aircraft.

A.F. Shoemaker, senior market development engineer with Corning's Advanced Products Department, said the command-break glass results from techniques developed for chemical strengthening of glass. In this process, the glass is given a surface compression layer. Penetration of this layer releases a predetermined amount of energy. The chemical strengthening can be controlled to the point where strength of the glass, depth of its compression layer and particle size of the broken glass can be varied over a wide range.

In the experimental canopies, for example, the glass is tailored to break into particles no larger than 0.004 of a

square inch. Disintegration of the entire canopy is designed to occur in less than five-tenths of a second. To meet the mechanical loads expected in flight from both aerodynamic and internal pressurization, a strength of 35,000 psi was developed in the glass. The surface compression layer also provides protection against accidental impact and abrasion.

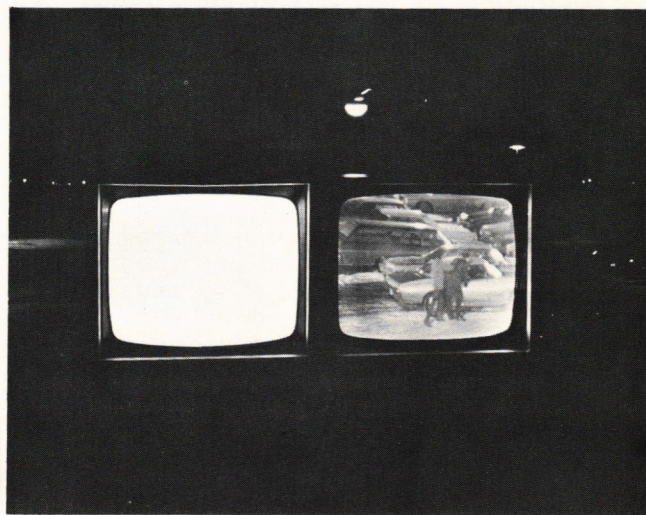
Two types of canopies were studied by Air Force. One canopy system has two layers of 0.085-inch thick glass separated by an air gap. Broken particles in this canopy are blown away. The second system features two plies of glass with a thin plastic interlayer to retain broken particles.

MOTOROLA INTRODUCES AUTOMATIC DAY OR NITE CCTV CAMERA

Motorola has introduced a closed circuit television camera which can be compared to the human eye in its ability to automatically adapt to light variations from full daylight to darkness.

Without a single adjustment, the new camera provides a minimum of 500 lines (the average home TV receiver has 300 lines horizontal resolution) horizontal resolution between 0.05 foot candles scene illumination (similar to moonlight conditions) and 8,000 foot candles (the equivalent of bright sunlight).

The ability to electronically adapt to a full range of light variations eliminates the need for either the additional night camera and associated hardware required with a two-camera system, or the conventional lighting usually required for night-time surveillance which typically costs between \$30,000 and \$50,000. In addition to this built-in cost reduction feature, a specially designed 10:1 zoom lens, locked



Dimly lit parking lots or subway stations used to be the criminal's favorite spot for an assault or robbery. Now, thanks to a new 24-hour closed-circuit television camera developed by Motorola, a guard can monitor even the darkest location and intervene at the first sign of trouble.

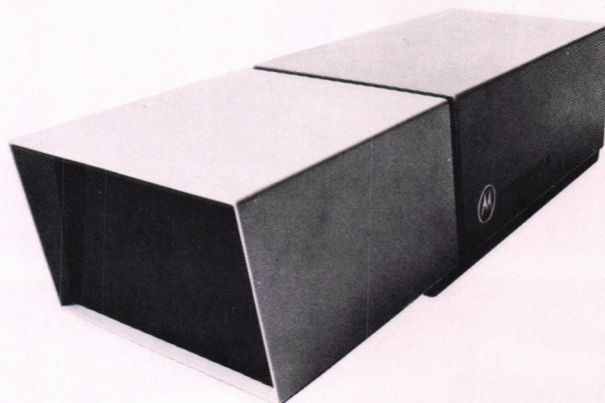
interlace for the sharpest possible picture, a completely enclosed all-weather housing and an unprecedented one-year warranty on all parts and labor are all included in the \$13,350 price of the unit.

The characteristics of the camera make it ideal for security surveillance of parking lots, loading docks, warehouses, rail yards, subways, freight terminals or any large, poorly lighted area.

The unit is designed to meet the same rugged environmental conditions of Motorola's heavy duty industrial CCTV camera, and its modular construction provides maximum simplicity of maintenance. It can be mounted on a pan/tilt unit or an environmental camera mount and is compatible with all existing closed circuit television systems.

The exceptional flexibility of Motorola's new camera is the result of two proprietary technological advances made by the company. One is the method Motorola developed to bond the image intensifier to the fibre optics face-plate of the vidicon tube, and the other is the attenuation technique which significantly improves camera reliability by providing

optimum protection of the vidicon in exceptionally high illumination situations.



Motorola 24-hour closed-circuit television camera can be compared to the human eye in its ability to automatically adapt to light variations from full daylight to darkness.

Research opportunities in highway engineering

The Asphalt Institute suggests projects in five vital areas

Phenomenal advances in roadbuilding techniques during the past decade have made it clear that continued highway research is essential.

Here are five important areas of highway design and construction that America's roadbuilders need to know more about:

1. Rational pavement thickness design and materials evaluation. Research is needed in areas of Asphalt rheology, behavior mechanisms of individual and combined layers of pavement structure, stage construction and pavement strengthening by Asphalt overlays.

Traffic evaluation, essential for thickness design, requires improved procedures for predicting future amounts and loads.

Evaluation of climatic effects on the performance of the pavement structure also is an important area for research.

2. Materials specifications and construction quality-control. Needed are more scientific methods of writing specifications, particularly acceptance and rejection criteria. Additionally, faster methods for quality-control tests at construction sites are needed.

3. Drainage of pavement structures. More should be known about the need for sub-surface drainage of Asphalt pavement structures. Limited information indicates that untreated granular bases often accumulate moisture rather than facilitate drainage. Also, indications are that Full-Depth Asphalt bases resting directly on impermeable subgrades may not require sub-surface drainage.

4. Compaction and thickness measurements of pavements. The recent use of much thicker lifts in Asphalt pavement construction suggests the need for new studies to develop and refine rapid techniques for measuring compaction and layer thickness.

5. Conservation and beneficiation of aggregates. More study is needed on beneficiation of lower-quality base-course aggregates by mixing them with Asphalt.

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operator and logs both the nature of the malfunction and the operator's response to the alarm.

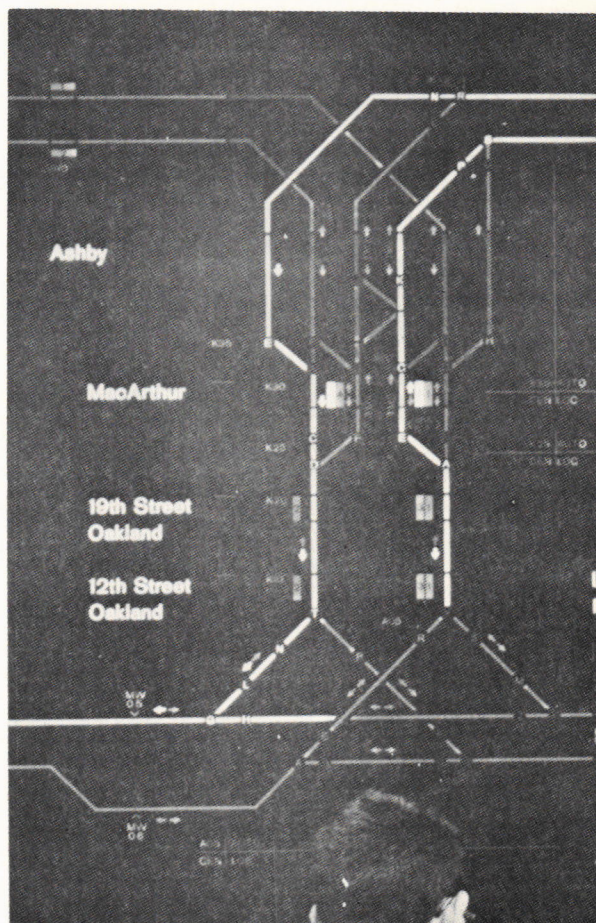
Another important job of the computer is to operate the three central display boards that show system status (Figure IV).



The operator at the train control console can display train operations at the console and on the display board above. The panel next to the telephone displays malfunction alarms. The keyboard can be used to request various data displays on the CRT above it. It is also used to enter minor program changes, such as a change in the nominal (20 second) dwell time at a passenger station. Typers to the left and right of the console make record copies of CRT-displayed information and of all alarms associated with train operations. (FIGURE V)

One such display board shows train operation. It is associated with a train control console (Figure V). The board is normally not illuminated; however, the console operator (equivalent to a train dispatcher) can display any one or combinations of the five lines (Southern Alameda, Downtown Oakland, San Francisco, Concord, & Richmond) or any specific interlocking* or combination of interlocking zones (Figure VI). A specific location will also light up when an alarm condition comes in from the field from that zone. A white illuminated tract section indicates non-occupancy, while red indicates occupancy.

*An arrangement of apparatus controlling switches, signals, and train movements, so interconnected that functions must occur in proper sequence. It permits train movements over controlled routes only if conditions are safe.

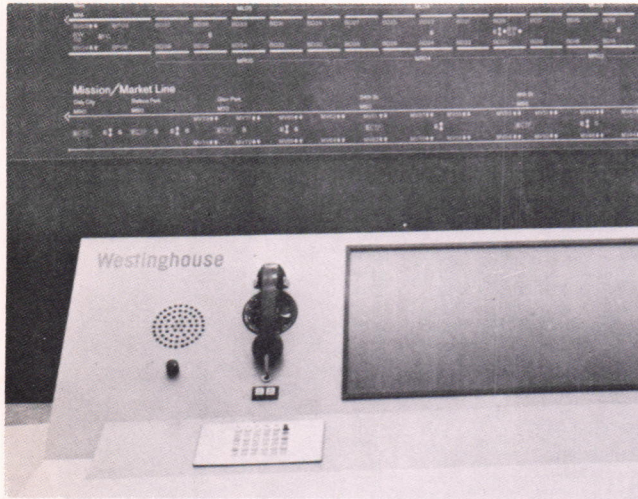


Track sections on the train control display board are illuminated by console operator. (FIGURE VI)

In general, the lengths of the track zones shown on the board do not reflect actual distances; rather, they represent functional zones: station zones, interlocking zones, interlocking approach zones, and turnback zones.

The train control console operator can also talk to the individual trains via radio, and he can make announcements at passenger stations.

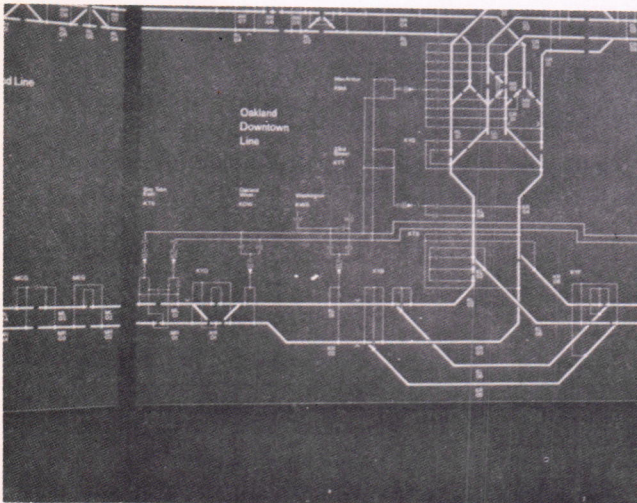
A second console is used to control system support facilities, which are located mostly underground and include such things as ventilation dampers, fans, and water pumps. The display board behind this console shows the operational status of these facilities (Figure VII) and also displays alarm conditions like station trouble, fire, or communications failure. In addition, this board shows the occupancy of each 1000-foot section of the tube under the San Francisco Bay. Emergency telephones located frequently through the underground sections, in station agents' booths, and at yards terminate at this second console.



The panel on the left of the support facilities console displays malfunction alarms; the one on the right is the screen for a rear slide projector. BART intends to reduce facilities' drawings to slides and store them for instant viewing. An adjacent typer make a printed record of alarms, and the display board shows equipment status. (FIGURE VII)



The computer room includes the two Prodac 250 computers housed in the cabinets on the right. The on-line unit supervises scheduling and monitors system operation; the standby unit takes over automatically if trouble develops in the on-line unit. (FIGURE IX)



Electrification control console has a panel for displaying alarms, a keyboard for entering operator commands, and an associated typer for recording all alarms. The display board behind the console shows the status of BART's electric power system. (FIGURE VIII)

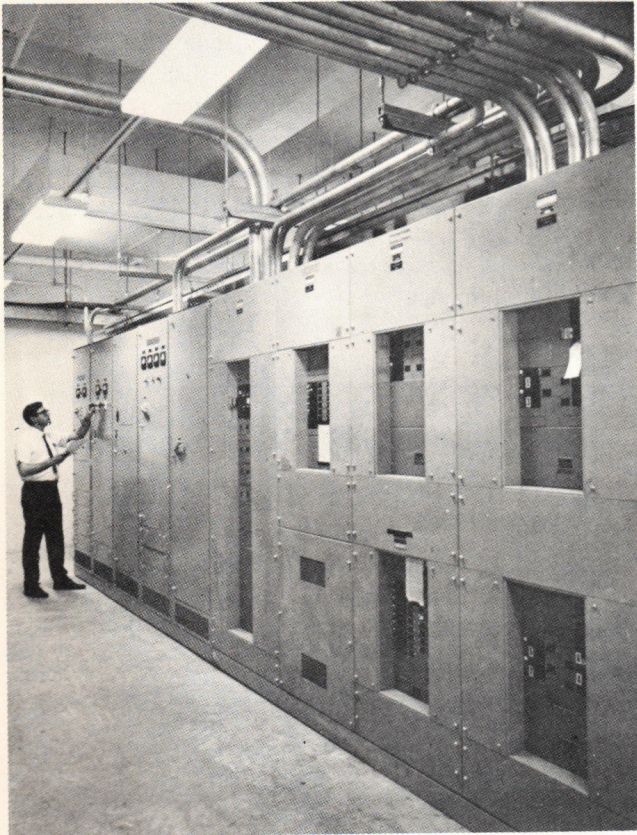
A third console and display board serve the system's electrification facilities (Figure VIII). They correspond to the conventional power-controller or power-dispatcher position in an electric utility or electric railroad facility. Among the major items they monitor and display are the status of the high-voltage and low-voltage circuit breakers and the power contact rails.

The computer room (Figure IX) is adjacent to the control room behind the display boards. Besides all the automatic functions assigned to it, the computer processes the manual commands from the console operators to the train-control, electrification, and support facilities. It converts instructions typed on the keyboards at the operator consoles into proper data words and passes them on to the data transmission system. Likewise, all incoming data is routed through the computer, where it is analyzed and appropriate action is taken (for example, changing a track section on the display board from white to red to indicate occupancy).

Programs are entered into the computer through, perhaps, the most widely known computer language, FORTRAN IV, making it relatively easy for BART programmers to communicate with it. Based on their importance, program routines are assigned one of three class levels. The Executive level is devoted to the most critical programs required both by the computer and the BART system; these programs normally remain fixed and may only be altered by an authorized person. The Resident Foreground level is devoted to high-priority programs which will usually require periodic update, but which are frequently used in the control process. The Background level is devoted to the storage of data and to low-priority programs which have only periodic use.

Each of the Prodac 250 computers has a high-speed core memory capacity of 24,000 words in its main frame. About 25 percent of this high-speed memory is devoted to programs of the first two class levels, with the remainder kept available for the processing and temporary storage of

the data and other program routines. The computer assigned to on-line operation has a disc for bulk storage with an additional 375,000-word capacity. Because some



Power inverter equipment assures that BART central control operations won't be disturbed by power interruptions. (FIGURE X)

additional off-line work, such as train-control simulation, is done solely by the standby computer, it has a much larger, 1,500,000-word bulk storage disc capacity.

Support equipment such as the telemetry terminals and electric power distribution equipment is located on the floor below the control and computer rooms. To ensure operation of the complex in case of power failure, an uninterruptable power supply is also located there. It uses batteries and solid-state inverters, (Figure X), to maintain a smooth flow of 60 Hz a-c power to all essential operating equipment during any power interruption up to two hours.

OPTIMIZATION OF SYSTEM OPERATION

Probably the most important and valuable function of the BART central computer control is its unique ability to supervise operation of the network to see that daily train schedules that minimize operating costs are maintained as closely as possible, while at the same time meeting service standards.

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TRAIN 105 DEPARTED FROM A40 AT 130223
TRAIN NOW RUNNING AT P.L. 1
TRAIN PREDICTED TO ARRIVE AT A30 AT 130403
TRAIN WILL HAVE A RANDOM DELAY OF 10 SECONDS
TRAIN BEHIND SCHEDULE BY 152 SECONDS
DISTRIBUTE HEADWAYS OF TRAINS AHEAD OF THIS TRAIN
AT CP 4 OFFSET TRAIN 104 BY 90 SECS
OFFSET THEOR. SCH. OF TRAIN 104 IMMEDIATELY BY 101 SECS
A LINE, REVERSE DIRECTION, TRAIN SERIAL NUMBER 104
-104 124500 124544 124604 124754 124754
124838 124858 125048 125048 125132 125157
125347 125347 125431 125451 125641 125711
125755 125755 125945 130005 130155 130155
130239 -130349 -130513 -130513

TRAIN 306 ARRIVED AT M55 AT 130231
TRAIN 306 DEPARTED FROM M55 AT 130231
TRAIN CONTINUES RUNNING AT P.L. 2
TRAIN PREDICTED TO ARRIVE AT M50 AT 130315
TRAIN BEHIND SCHEDULE BY -0 SECONDS
CONTINUE WITH EXISTING SCHEDULE

TRAIN 305 ARRIVED AT M20 AT 130233
NEW MINIMUM DWELL 14 SECS
DWELL AT THIS STATION WILL BE 20 SECS
TRAIN WILL HAVE A RANDOM DELAY OF 6 SECONDS
TRAIN PLANNED TO RUN AT P.L. 2
TRAIN BEHIND SCHEDULE BY -0 SECONDS
CONTINUE WITH EXISTING SCHEDULE

TRAIN 103 ARRIVED AT K30 AT 130239
NEW MINIMUM DWELL 17 SECS
DWELL AT THIS STATION WILL BE 30 SECS
TRAIN PLANNED TO RUN AT P.L. 2
TRAIN BEHIND SCHEDULE BY -0 SECONDS
CONTINUE WITH EXISTING SCHEDULE

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This portion of a printout from simulation of a three-line system shows what the trains were doing and what strategies applied. Such information provided the basis for optimizing the BART control. (FIGURE XI)

A control strategy that could perform these optimizing functions was developed and tested using a rapid transit simulation program (Figure XI) and a large digital computer.

The program describes the real-life system. It includes a model, which is essentially a tabular representation of the BART system corresponding to the discrete locations where information for control is obtained and where control adjustments can be made.

The simulation program proved invaluable in analyzing the BART system and in formulating and testing the control strategy logic. Even for simple control adjustments like changes in permitted maximum speed or station dwell time, pitfalls were encountered that otherwise wouldn't have shown up until much later when changes would have been difficult or impossible. Now kept in the backup computer in the central control complex, the simulation program will continue to serve BART each time it wants to test out any proposed change in system operation, especially as passenger load demands change in future years.

The system control strategy developed for BART starts by establishing, at the beginning of each day, a theoretical schedule of arrival and departure times from 53 critical locations — 34 stations plus 19 other locations at which a routing change or train sequence change may be made (Figure XII). A schedule is established at these locations for each of the 105 trains which may be operating on the

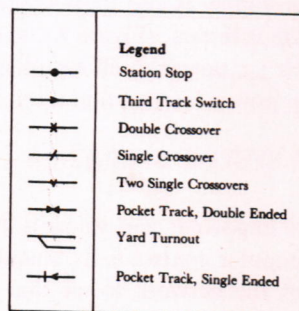
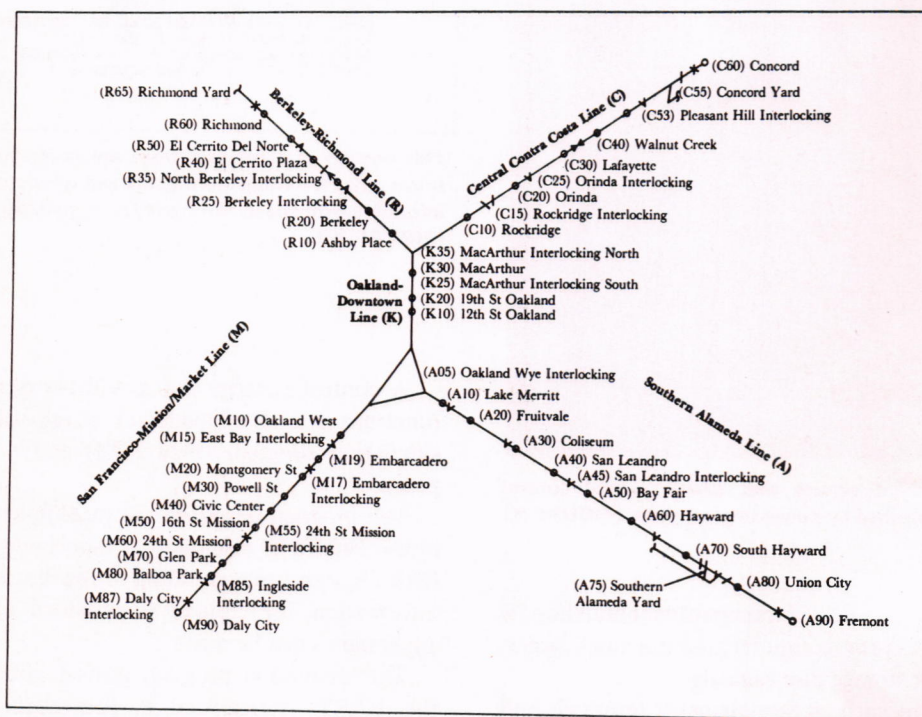
network. Each train identifies itself as it arrives at a critical point and its actual arrival time is compared to the theoretical arrival time by the central computer.

Corrective strategies try to keep the trains on time at the critical points to ensure proper sequencing of trains, while allowing some latitude at other points to meet service requirements. If sequence can't be maintained, the strategy is to try to remedy the situation by the time the train reaches the next critical point to ensure system stability.

The control strategy logic, then, has the task of determining which corrective action will result in the least favorable consequences. These are defined to mean that a uniform gap (time between departure of one train and arrival of the next at a station) is more important than the

theoretical schedule arrival and departure times. This means possibly slowing trains ahead of a delayed train to make the gaps more uniform. To bring the system back to theoretical schedule, all trains are dispatched from the turnback at the theoretical schedule dispatch time.

Occasionally a poorly performing train may call for a special strategy. The ideal strategy in such a case is to remove the poor performer from the system as quickly as possible and substitute a good train. This may require as much as 30 minutes, during which service on the entire system is slowly degrading. To reduce the effects of such an occurrence, BART has placed storage yards near three end-of-line terminals and has included an extra side track at the Daly City terminal.



Critical control locations, designated on this system schematic by a letter and two digits, are points at which train routing or sequence changes can be made. (FIGURE XII)

Knowledge today is increasing at a rate that can best be described as following a curve defined by the equation $Y = a^x$. And we're just about reaching the steep slope of that curve.

We're not trying to discourage you. We're just suggesting that when you think about your career, you give some thought to how you're going to keep up with that curve.

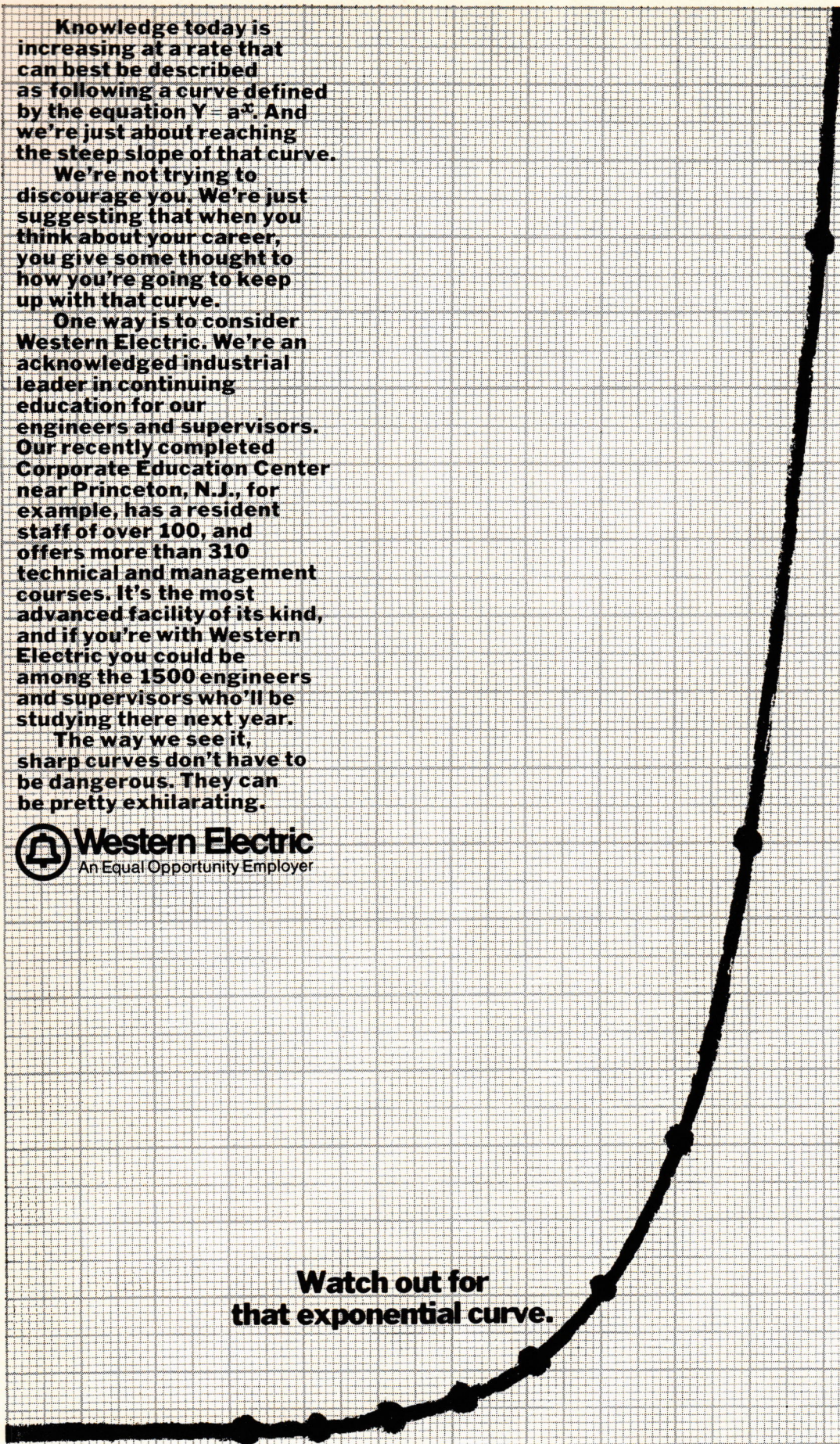
One way is to consider Western Electric. We're an acknowledged industrial leader in continuing education for our engineers and supervisors. Our recently completed Corporate Education Center near Princeton, N.J., for example, has a resident staff of over 100, and offers more than 310 technical and management courses. It's the most advanced facility of its kind, and if you're with Western Electric you could be among the 1500 engineers and supervisors who'll be studying there next year.

The way we see it, sharp curves don't have to be dangerous. They can be pretty exhilarating.



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An Equal Opportunity Employer

**Watch out for
that exponential curve.**



Even if you don't like the air you breathe, you can't stop breathing.

When was the last time you went out for a breath of fresh air and got it? How long has it been since the sky looked really blue?

Every day, our cities dump hundreds of thousands of tons of waste into the air. Carbon monoxide. Sulfur dioxide. Fluoride compounds. And plain old soot.

If something isn't done about air pollution in your lifetime, it may cut your lifetime short.

Air pollution can be controlled. The key is technology. Technology and the engineers who can make it work.

Engineers at General Electric are working on the problem from several directions.

Rapid transit is one. In many cities, the automobile causes more than half the air pollution. In some cities, as much as 90%. But engineers at GE are designing new equipment for rapid-transit systems, encouraging more people to leave their cars in the garage.

Another direction is nuclear power. General Electric's engineers designed the very first nuclear power plant ever licensed. A nuclear plant produces electricity without producing smoke. And as the need for new power plants continues to grow, that will make a big difference.

There are other ways General Electric is fighting air pollution. Maybe you'd like to help. We could use your help. But don't expect to come up with an overnight solution to the problem.

The solution will take a lot of people, a lot of talent and a lot of time. You'll breathe easier — once you get started.

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